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Residue impacts on runoff and soil erosion for different corn plant populations

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ABSTRACT

The year to year carry-over effects of biomass additions under different plant populations on runoff and erosion are unclear. The objective of this study was to quantify the impact of different plant populations on residue cover to elucidate the effects of residue cover on runoff and erosion. The residue management system involved shredding of corn (maize) biomass after harvest, incorporating the residue in the spring, and leaving the land fallow until it was no-till planted the following spring. Runoff and soil losses were measured on 18 runoff plots with plots arranged in two areas with each having three randomized treatments (0%, 50%, and 100% plant population) with three replications. The two areas were managed as a fallow/no-till corn rotation in two cycles of alternating years. Surface residue cover was highly dynamic with significant changes between cycles and seasons in response to the management practices. The annual soil losses were reduced by 47% and 54% for the 50% and 100% plant populations, respectively compared to the control. However, the annual soil loss even for the 100% plant population was still nearly seven times the tolerable soil loss limit of 7 ton ha^{-1}. The normal erosion protection afforded by no-till practices was lost by the incorporation of residue the previous year.

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1. Introduction

Soil erosion results in the degradation of quality and long-term productivity of landscapes and introduces sediment and associated contaminants into surface waters. Predicting and controlling the movement of sediment from agricultural lands requires knowledge of how soil and crop management practices, such as no-tillage and residue management, affect soil erosion processes.

Considerable research has been conducted on the importance of residue cover on runoff and erosion (Steiner, 1994). Surface residue is known to provide protection from raindrop impact, slow runoff and create small ponds where sediment can be deposited and runoff can infiltrate (Alberts and Neibling, 1994). Gilley et al. (1986) observed, by removing corn residue then returning the residue to the surface at different rates, that runoff and soil loss decreased with increased surface residue. Baumhardt and Lascano (1996) found that a minimum amount of surface residue was needed to effectively intercept raindrops and that residue amounts above a threshold of 2.4 Mg ha^{-1} had no further impact on raindrop impact. Thus, surface residue results in decreased runoff and erosion (McGregor et al., 1990a,b) to the degree that 100% surface cover has negligible erosion, 50% cover reduces erosion by around 80%, and only 10% surface cover reduces erosion by 30% (Moldenhauer and Langdale, 1995). However, less is known about the longevity of these effects and the effects of tillage incorporation.

Baumhardt and Lascano (1996) found that the enhanced infiltration capacity from surface residue declined with time due to residue weathering. Residue

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loss may also be due to transport off the plot by wind or water, consumption by animals, or other mechanisms. They noted that initial residue additions to bare soil surfaces increased the infiltration but subsequent additions had minimal effect. Not only does weathering of the surface residue reduce its effectiveness but the incorporation of residue can significantly reduce the erosion and runoff control benefits. McGregor et al. (1990a,b) conducted laboratory and field studies suggesting that while surface residue significantly reduces soil loss, newly incorporated residue has minimal effect on runoff and soil loss. This is in contrast to the traditional concept established by Wischmeier and Smith (1978) that credits a 5.4% reduction in soil loss for each ton per hectare of incorporated corn.

The differences in findings regarding the benefits of incorporated residue may be related to the timing of the incorporation and the impact of tillage on other soil properties. Not only does surface residue cover increase with time under no-till (NT) systems, but soil properties such as soil structure improve with time in response to increases in organic matter and lack of disturbance. Tillage, following a period of NT, incorporates the surface residue and alters these improved soil properties in a dynamic fashion. Wilson et al. (2004) studied the carry-over effects from one year to the next of residue and tillage management decisions on runoff and erosion. They conducted simulated rainfall experiments on long-term conventional-till and NT plots with residue left on the surface, residue removed immediately before rainfall and residue removed and the land kept fallow without residue cover for a year before rainfall. Residue removal resulted in significantly sooner runoff and greater soil losses (SL) under NT. The benefits of NT history were not completely lost immediately after conversion to conventional tillage but were fully lost within 1 year of residue removal (Wilson et al., 2004). Residue removal on long-term NT plots was an attempt to isolate the effect of loss of surface residue without the complication of soil disturbance by incorporation. However, Wilson et al. (2004) did not address the dynamics of the organic matter added to the soil by incorporation. Brown et al. (1990) studied the effect of residue 1 year after incorporation on erosion rates using a rainfall simulator. They found for freshly tilled soil that residue did decrease erosion even a year after incorporation, with the degree of reduction increasing as the amount of incorporated residue increased. However, natural consolidation, due to lack of soil disturbance, had a more prominent effect than residue incorporation, effectively masking the contribution of different rates of residue incorporation from the previous year.

Given that the amount of residue loss, as well as the dynamics of the surface residue cover losses, due to weathering and incorporation affect erosion rates, management of residue cover for corn becomes a delicate balance between biomass production, silage harvesting, and tillage incorporation. The impact of residue losses on erosion is of particular concern with regard to the use of biomass for biofuel production. Grande et al. (2005) addressed the issue of silage production by comparing grain-only harvest to conventional silage harvest (form of residue removal), and to silage harvested at a greater cut height (less residue removed). They found no differences in sediment concentrations between silage cutting heights. Sediment export was higher for silage harvest than for grain-only harvest due to residue removal regardless of the silage harvest approach. This suggests that differences in biomass production may also have a limited impact on erosion control. However, no study has addressed the relationship of runoff and erosion to plant population and the associated residue cover.

The objective was to establish the temporal relationships of runoff and erosion to residue cover prior to and following incorporation of biomass produced from three levels of corn plant populations: 100% (normal recommended population), 50%, and 0% (fallow).

2. Materials and methods

The study was conducted at the North Mississippi Branch of the Mississippi Agriculture and Forestry Experiment Station at Holly Springs, Mississippi. There were two areas (1 ha each about 1 km apart) of nine plots each arranged in randomized complete block design with three replications and three treatments for a total of 18 plots. Soils on both areas were classified as Loring silt loam, fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs. Plots were 3.66-m wide by 10.67-m long with slopes ranging from 2% to 4.5% for an average of 3.25%. The lower end of each plot had an endplate and runoff collector that routed water into an H-flume equipped with FW-1 water level recorder and an N-1 Coshocton wheel sampling device. Measured soil losses were adjusted (SL_a) for each individual plot's slope (θ_{ps}) to the average slope (θ_{as} = 3.25%) according to (McCool et al., 1987):

$$SL_a = \frac{SL(10.8\sin\theta_{as} + 0.03)}{(10.8\sin\theta_{ps} + 0.03)}. \quad (1)$$

For each block, the treatments were three levels of plant population (0%, 50%, and 100% corn plant populations) with three replications for each treatment. Normal corn (maize) planting rates were grown on the 100% population treatment. The 50% plant population was obtained by planting at the normal rate followed by thinning after emergence to 50% plant population. Thinning to 50% plant population was done manually at least 1 month after planting. The bare (0% corn population) treatment was obtained by not planting. Areas were managed as a fallow/no-till corn rotation during 1990–1995 and all plots were in no-till corn in 1989. Only data during water year 1992 through water year 1995 will be reported. During each year, one area was in fallow while the other area was in corn and the following year these were reversed. Area 1 was fallow in 1993 and 1995, whereas Area 2 was fallow in 1992 and 1994. Thus there were two cycles (of 2 years each) of measures for Fallow and Crop (non-fallow) management practices. Cycle A corresponds to years 1992 and 1994 (with Area 1 cropped, Area 2 fallow), and Cycle B to 1993 and 1995 (with Area 1 fallow, Area 2 cropped). See Fig. 1 for more details.

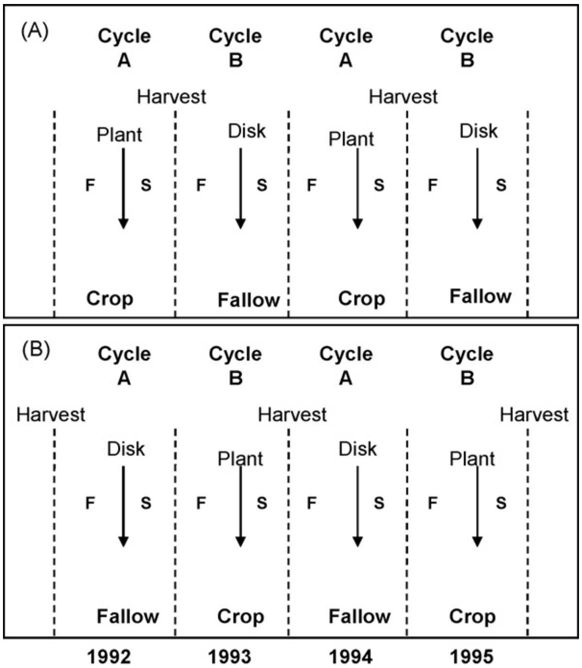

Fig. 1. Time line diagram of management practices by season (F and S), cycle (A and B), and management period (fallow and crop) for Area 1 (A) and Area 2 (B).

Corn (Pioneer 3154) was no-till planted on 95.4-cm row spacings. Planting operations included broadcasting 560 kg ha^{-1} of 13-13-13 fertilizer, and application of Atrazine, Dual, and Gramoxone at recommended rates. All plots were kept free of grasses and weeds during the study period with the use of recommended chemicals. Planting dates were 3 April 1992 and 14 April 1994 for Area 1, and 12 April 1993 and 5 April 1995 for Area 2. During crop years, corn was side-dressed in May with 280 kg ha^{-1} of ammonium nitrate. Following grain harvest in September, corn stalks were shredded and left on the surface until the following April when all plots in the area were disked twice and section harrowed. Harvesting and shredding of stalks occurred on 10 September 1990, 17 September 1992, and 14 September 1994 for Area 1, and 11 September 1991, 23 September 1993, and 12 September 1995 for Area 2. Incorporation of residue by disking for the area in its Fallow management period occurred at the same time as planting for the other area in its Crop period.

Rainfall was measured adjacent to Area 2 with a weighing bucket rain gauge. Storm events were separated by a period of 6 h or more with less than 2.54 mm rainfall. Runoff was measured on a storm event basis by the stage recording and the depth of water in the collection vessel was used as a backup estimate of runoff knowing that the Coshocton wheel samples one hundredth of the runoff. Monthly totals for runoff and soil loss were computed. Residue cover was determined monthly by the line-transect method (Laflen et al., 1981).

Fig. 1 provides a time sequence of the management period associated with cycle and seasons. Year was divided into two seasons (S and F) with the S season corresponding with the period of residue incorporation (disking/planting) and the F season corresponding with the application of new residue (harvest/shredding). The experimental design was analyzed as a randomized complete block with split plots. The main treatment was three plant populations with three replications and subtreatments of cycle (92 & 94 for Cycle A and 93 & 95 for Cycle B) and management period (Fallow and Crop). Data were combined for management periods (Fallow and Crop) and cycles (A and B) and analysis of variance (ANOVA) was performed for each season. Proc Mixed procedure (SAS, 1999) was used for analysis of variance and mean comparisons. Statistical significance was set with Type II error rates of 0.05 or less.

3. Results and discussion

3.1. Plant and residue response

Plant population means of plant and residue responses for each cycle are shown in Table 1. When a log transformation was used in the analysis of variance, the means were back-transformed to the original scale in Table 1. The 0% plant population treatment was not included in analysis of variance in order to meet the assumption of common variance among the treatments. As expected, all plant variables (plant population, biomass, yield, and residue cover) were greater for the 50% and 100% plant population treatments than zero which was by design the value for the control (0% treatment). Table 1 indicates significant differences between 50% and 100% plant population treatments for both cycles. The differences in plant population between the 50% and 100% treatments were significant even though the 50% treatment averaged closer to 60% of the population of the 100% (normal stand) treatment. There was also a significant cycle by treatment interaction for yield. Yield was significantly greater for 50% compared to 100% treatment for Cycle A but not Cycle B. Since fallowed plots were not

Table 1
Arithmetic means for plant population (plants ha^{-1}), biomass (ton ha^{-1}), and grain yield (ton ha^{-1}) for the two crop years of the study per Cycle, and geometric means for residue cover (%) over all 4 years of the study for treatments 0%, 50%, and 100% plant populations

Treatments	Plant population (plants ha^{-1})		Yield (ton ha^{-1})		Biomass (ton ha^{-1})		Residue cover (%)	
	Cycle A	Cycle B	Cycle A	Cycle B	Cycle A	Cycle B	Cycle A	Cycle B
0	0	0	0	0	0	0	0.2	0.3
50	33380 b	47280 b	14.4 a	8.8 a	7.51 a	6.26 a	15.6 a	18.9 a
100	58260 a	74290 a	10.3 b	10.6 a	7.07 a	6.33 a	16.3 a	19.6 a

Based on ANOVA *F*-test, different letters indicate that treatments 50 and 100 are significantly different at the 0.05 level. Treatment 0 was not included in ANOVA in order to meet assumption of common variance among treatments.

used, differences due to cycles were due to environmental conditions only. The contradiction between population and yield is at least in part due to differences in weather between crop cycles. Cycle A had a crop grown in 1992 and 1994 while Cycle B had a crop grown in 1993 and 1995, with precipitation during the growing season (May–September) totaling 765 and 635 mm, respectively, for Cycle A, and 536 and 551 mm, respectively, for Cycle B. More dramatic were the differences in precipitation during the May and June months which totaled 272 and 371 mm for Cycle A, and 135 and 155 mm for Cycle B. Thinning did not result in reduced yield as differences between the 50% and 100% treatments were not significant for Cycle B.

For biomass there was a significant treatment effect but no cycle effect or cycle–treatment interaction. The biomass produced for the 50% and 100% treatments were significantly higher than the control but differences between them were not significant. The biomass was shredded after harvest thereby producing residue cover. Relationships between residue cover (% residue area per surface area) and residue biomass (mass per surface area) are complex and depend upon the plant species, tillage operation, and decomposition rates (Gregory, 1982; McCool et al., 1995; Steiner et al., 2000). Some erosion models use residue mass to estimate erosion while others use, such as RUSLE2, use surface cover as input and compute residue mass. There were no statistical differences in the surface residue cover between the 50% and 100% treatments over the 4-year period. Clearly, the residue cover changed significantly during the study (Fig. 2) with sharp increases after harvest and shredding of stalks in September, followed by gradual decreases as a result of residue loss. The sharp decrease after incorporation in the spring of the following crop year resulted in minor differences in residue cover between cycles until the subsequent harvest. Thus, there appeared to be a seasonality effect to the residue cover data as indicated by the demarcations in Fig. 2.

To determine if a seasonality effect to residue cover exists, the crop year was separated into two seasons: April through August (season S), and September through March (season F) associated with the timing of disking/planting

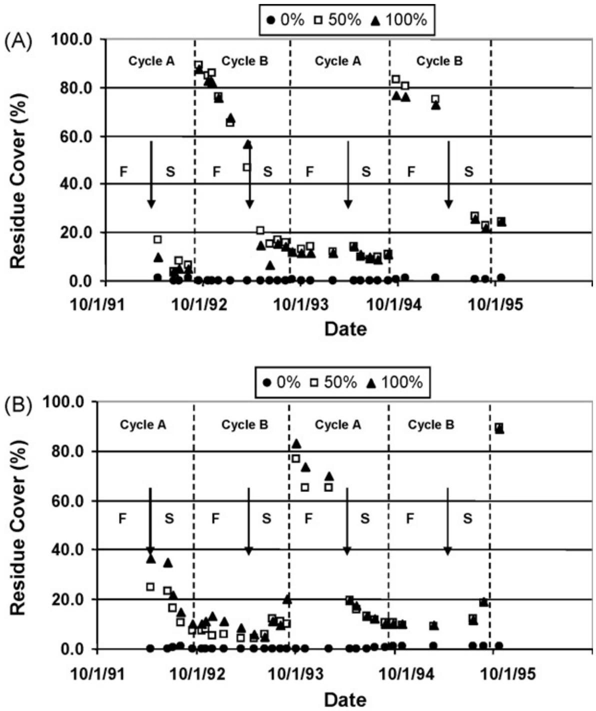

Fig. 2. Surface residue cover changes with time during the 4-year study period for treatments 0%, 50%, and 100% with cycle distinguished by the dashed lines and seasons by arrows for Area 1 (A) and Area 2 (B).

and harvesting/shredding. Additionally, the cycles were distinguished by management period (Fallow–Crop period). Statistical analyses for residue cover by season and management period (Table 2) were for treatment 50% and 100% only. Residue measurements were transformed using a log transformation to meet assumptions of homogenous variance among treatments and normal distribution required by analysis of variance. Means presented in Table 2 are transformed back to the original scale (geometric means). Significant effects were observed for management period, and season along with significant

Table 2
Geometric means for residue cover (%) at the end of the summer (S) and fall (F) seasons for Cycle A (1992 and 1994) and B (1993 and 1995) along with the ratio of the fallow to Crop period by season

Treatments	Fallow		Crop period		Average	
	Cycle A		Cycle A		Ratio	
	F	S	F	S	F	S
0	0.4	0.2	0.4	0.2		
50	78.3 a	15.5 a	16.4 a	8.7 a	4.69	1.78
100	81.8 a	18.7 a	16.8 a	7.8 a	5.14	2.40
Treatments	Fallow		Crop period		Average	
	Cycle B		Cycle B		Ratio	
	F	S	F	S	F	S
0	0.4	0.1	0.4	0.4		
50	75.8 a	20.1 a	7.6 a	10.2 a	9.97	1.97
100	74.6 a	16.6 a	9.9 a	10.1 a	7.54	1.64

F-test compared treatment 50 to treatment 100. Different letters indicate that treatments are significantly different at the 0.05 level. Treatment 0 was not included in ANOVA in order to meet assumption of common variance among treatments.

season–management and cycle–management–treatment interactions but no significant cycle effect. The 50% and 100% treatments showed significantly higher residue amounts than the control for all combinations. There were no significant differences between the 50% and 100% treatments at the 0.05 level, however, differences between these treatments would have been significant at the 0.08 level for the S season during the Fallow period.

Comparisons in Table 2 are between treatments only (within seasons–cycles–management periods). The Fallow period could not be tested against the Crop period due to the experimental design not including randomization of plots for this effect. However, the fallow effect was also represented as a treatment effect since the control (0%) was a fallow treatment that was statistically compared with the 50% and 100% treatments. Additionally, differences in Fallow to Crop periods are evident by calculating the ratios for each treatment within season, Table 2. The residue cover was 6.8 times higher for the Fallow than the Crop period during the F season and 1.9 times higher during the S season for the 50% and 100% treatments. It is obvious that the F season for the Fallow management period had higher residue cover than the other season–management combinations (Table 2). This is because the F season for the Fallow period occurs immediately after harvest and shredding of corn biomass. The residue cover does follow the expected trend of decreasing cover in the S-Fallow period due to tillage incorporation, then continued decrease in cover during the F and S Crop periods due to weathering of residue. As a result, the ratio of F to S season averaged 4.4 for the Fallow period as compared to 1.4 for the Crop period.

3.2. Rainfall and runoff response

The 4-year annual rainfall was 1405 mm, which is only slightly higher than the 30-year average of 1372 mm for this region (McGregor et al., 1987). The rainfall erosion index (EI) is the product of the individual storm's kinetic energy (KE) and the maximum rainfall intensity (I) over a 30-min period. The KE, as defined by Wischmeier and Smith (1978), is

$$KE = 916 + 331 \log_{10} I \qquad (2)$$

The EI, expressed as MJ mm ha^{-1} h^{-1}, was computed for each storm event and summed by month. The monthly EI averaged 7713 MJ mm ha^{-1} h^{-1} which was higher than the 12-year monthly average EI of 7107 MJ mm ha^{-1} h^{-1} reported by McGregor and Mutchler (1983) for this location. Runoff and soil loss for this 4-year period should thus be slightly higher than the long-term average.

The variability in monthly runoff totals was high with r-square values ranging from 88% to 100%. Monthly runoff closely followed the rainfall pattern with r-square values exceeding 0.97. Treatment and season effects on runoff are more easily seen by computing the cumulative runoff with time, Fig. 3. Despite the large variability in monthly values, the seasonality of residue cover did appear to have some effect on cumulative runoff responses, as evident in Fig. 3. However, separation of treatments after 4 years was minor. Given that the biomass produced was slightly higher for Cycle A than Cycle B (Table 1), it was expected that Cycle A would have more residue cover and thus increased infiltration. However, Cycle A did not have more residue cover than Cycle B and in general, Cycle A exhibited greater runoff. In fact, the cumulative runoff was significantly higher for Cycle A than Cycle B for both Fallow and Crop periods during both S and F seasons, Table 3. The greater runoff for Cycle A than B despite no differences in residue cover is clearly a reflection of the greater rainfall as discussed earlier.

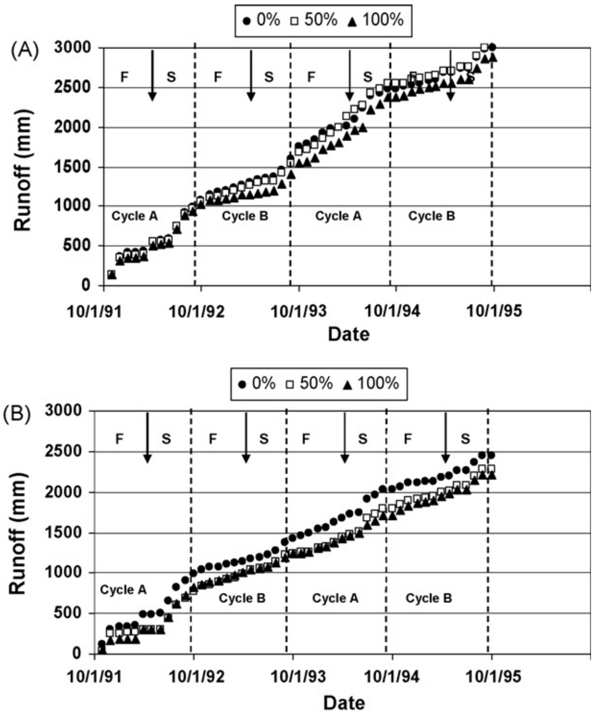

Fig. 3. Surface runoff with time during the 4-year study period for treatments 0%, 50%, and 100% with cycle distinguished by the dashed lines and seasons by arrows for Area 1 (A) and Area 2 (B).

While runoff differences between cycles did not follow the expected response to biomass production, differences in treatments within cycles, management periods, and seasons did generally follow the expected response. Runoff tended to be higher for the 0% plant population treatment than the 50% and 100% treatments (Table 3), but was only significantly different for the F season during the Fallow period and the Cycle B Crop period. Runoff was significantly lower for the 100% treatment than the 50% treatment for the Fallow period of Cycle B for the F season and the Crop period of Cycle B for the S season despite no differences in residue cover.

3.3. Soil loss response

Surface residue cover had more impact on soil loss, as expected, than runoff. As a result, the r-square values for the linear regression of monthly soil loss with monthly rainfall were slightly lower than for runoff with values ranging from 0.91 to 0.98. These factors resulted in

Table 3
Geometric means for cumulative runoff (mm) at the end of the summer (S) and fall (F) seasons for Cycle A (1992 and 1994) and B (1993 and 1995) along with the ratio of the fallow to Crop period by season

Treatments	Fallow		Crop period		Average	
	Cycle A		Cycle A		Ratio	
	F	S	F	S	F	S
0	374 a	413 a	536 a	493 a	0.70	0.84
50	259 b	403 a	548 a	445 a	0.47	0.90
100	260 b	376 a	463 a	497 a	0.56	0.76

Treatments	Fallow		Crop period		Average	
	Cycle B		Cycle B		Ratio	
	F	S	F	S	F	S
0	233 bc	305 b	160 c	231 bc	1.45	1.32
50	205 c	291 b	218 b	245 b	0.94	1.19
100	165 d	290 b	224 b	203 c	0.74	1.43

Different letters indicate that treatments within a column are significantly different at the 0.05 level.

significant treatment, seasonality, and cycle effects (Fig. 4) in the cumulative soil loss. Statistical analysis of the cumulative soil loss at the end of each season, revealed significant treatment effects and a significant management period–cycle interaction but the other interactions were not significant. The statistical analysis was then conducted by season and management period (Table 4). The soil loss was consistently highest for the 0% plant population treatment and differences between the 0% and the 50% and 100% treatments were generally significant. Soil losses were generally lowest for the 100% treatments but the only significant difference between the 50% and 100% treatment was for the Fallow period of Cycle A.

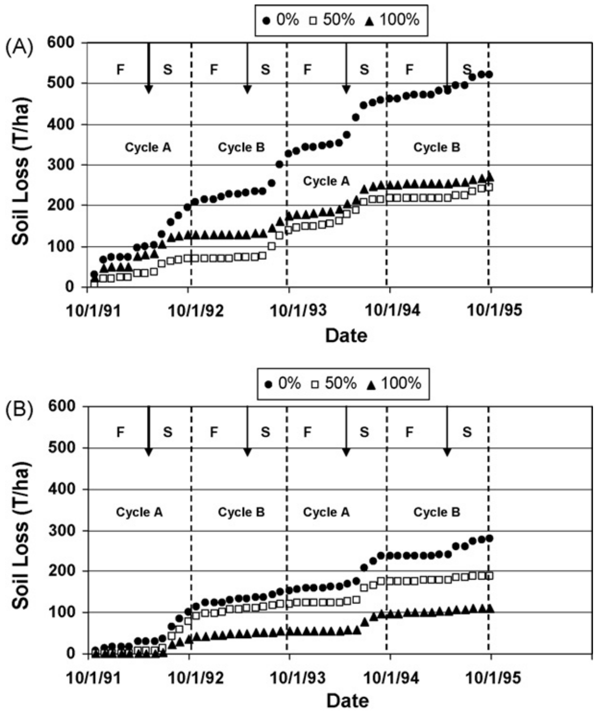

Fig. 4. Soil loss with time during the 4-year study period for treatments 0%, 50%, and 100% with cycle distinguished by the dashed lines and seasons by arrows for Area 1 (A) and Area 2 (B).

RUSLE2 utilizes a surface residue subfactor to account for an increase in soil loss as surface residue decreases. For the management conditions of this study, RUSLE2 estimated roughly a 25% increase in the soil loss ratio for each 10% decrease in surface residue cover due to decomposition losses. The impact of incorporation of residue by tillage is complicated by an increase in roughness; combined, the soil loss ratio computed by RUSLE2 for these conditions increased from 0.1 to 0.2 as surface residue cover decreased from 60% to 17% and the surface roughness subfactor increased from 0.2 to 1.0 due to tillage. Given that tillage occurred in the S season of the Fallow period, Fig. 1, these combined effects are reflected in the S to F ratios for soil loss for the Fallow period and not in their ratios for the Crop period. The cumulative soil losses were higher in the S than the F season regardless of the cycle and period (Table 4). The ratios of S to F season were much higher during the Fallow period than the Crop period, averaging 2.7, 14.7, and 28.0 for the 0%, 50%, and 100% treatments, respectively. This is because the F season of the Fallow period had the highest surface residue cover (Table 2), 82–75% for the 100% plant population, whereas the soil loss was minor, 0.9–1.4 ton ha^{-1} (Table 4). In contrasts, the soil loss was high during the S season of the Fallow period (>22 ton ha^{-1}) due to lower surface residue (<20%) and therefore the S to F ratio was high for the Fallow period. It is interesting to note while differences in surface residue between the 50% and 100% treatments were not significant, the impact on soil loss was dramatic as evidenced by the increase in the S to F ratio from the control to the 50% and 100% plant population treatments. Soil losses were also generally higher for the S season than the F season for the Crop period but to a lesser degree than for the Fallow period (Table 4). As a result, the ratios of S to F for the Crop period were lower for the 0%, 50%, and 100% treatments, averaging 1.9, 1.4, and 1.1, respectively. Guy and Lauver (2006) noted that NT and reduced till maintain previous crop residue thereby providing erosion control. This study demonstrates that residue must be managed synergistically with the reduced tillage system to exhibit this benefit. If residue cover is lost by weathering

Table 4
Geometric means for cumulative soil loss (ton ha^{-1}) at the end of the summer (S) and fall (F) seasons for Cycle A (1992 and 1994) and B (1993 and 1995) along with the ratio of the fallow to Crop period by season

Treatments	Fallow		Crop period		Average	
	Cycle A		Cycle A		Ratio	
	F	S	F	S	F	S
0	17.5 a	58.3 a	55.9 a	107.9 a	0.31	0.54
50	4.2 b	50.1 a	28.0 abc	43.8 bc	0.15	1.14
100	0.9 c	36.0 ab	38.1 ab	58.4 ab	0.02	0.62
Treatments	Fallow		Crop period		Average	
	Cycle B		Cycle B		Ratio	
	F	S	F	S	F	S
0	27.9 a	56.3 a	11.7 bc	22.9 c	2.38	2.45
50	1.9 bc	33.2 ab	8.8 c	10.2 d	0.22	3.77
100	1.4 c	22.2 b	8.1 c	4.9 d	0.17	4.53

Different letters indicate that treatments within a column are significantly different at the 0.05 level.

and/or incorporation prior to NT establishment then these benefits will not be realized.

Soil losses for Cycle A were higher than Cycle B during the Crop period for both seasons, Table 4. This is further evidenced by the ratios of Fallow to Crop period soil losses which averaged 0.76 and 0.16 for the three treatments for S and F seasons, respectively for Cycle A, but 3.58 and 0.92, respectively, for Cycle B. This is due to the greater runoff for Cycle A as a result of differences in rainfall.

The culmination of the imposed management practices was that annual runoff decreased only slightly (6.5% and 10.8%, respectively) from the 0% population with essentially zero residue cover to the 50% and 100% plant populations (Table 5). However, the plant population did have a significant effect on annual soil losses, reducing losses by 47%, and 54% for the 50% and 100% plant populations, respectively. Soil losses for the 50% and 100% treatments still exceeded the tolerable soil loss limit of 7 ton ha^{-1}. This is due in part to the higher than normal rainfall and EI values during this 4-year period of record. It is also a reflection of the loss of the reduction in surface cover due to weathering of surface residue during the F season following shredding and incorporation of the remaining residue in the subsequent S season. Plot-scale research such as the USLE size plots used in this study have been the foundation of soil erosion research and the development of codes such as RUSLE (Wischmeier and Smith, 1978). However, the rates observed at the plot scale do not represent the rate of soil loss at the catchment or watershed scales. Sheet and rill erosion dominate at the plot scale, whereas as the scale increases other processes may become dominant (Poesen et al., 2003). Much of the soil loss from hillslopes, i.e. plots, will be deposited at toe slope and depressional areas of catchments. However, runoff losses do not decrease and in fact may increase due to exfiltration, i.e. seepage, in such locations as the scale increases. Thus, convergent flow tends to increase with increased scale thereby facilitating a shift to ephemeral gully erosion and increased soil loss.

Table 5
Total annual runoff (mm $year^{-1}$) and soil loss (ton ha^{-1} $year^{-1}$) averaged over the two blocks with three replications in each ($n = 6$)

Treatments	Runoff (mm $year^{-1}$)		Soil loss (ton ha^{-1} $year^{-1}$)	
	Mean	S.D.	Mean	S.D.
0	768	102	111.6	40.8
50	720	119	59.0	23.0
100	693	98	51.7	23.5

4. Conclusions

The impact of reduced plant population and the corresponding impacts of residue management practices on runoff and soil loss were addressed. The residue management system involved shredding of corn biomass after harvest and leaving the residue on the surface until the spring when it was incorporated by disking, then leaving the land fallow until the following spring when corn was NT planted. Despite thinning the plant population to 60% (target of 50%) of the normal (100%) plant population, the biomass produced was not significantly different between these treatments but both treatments had significantly higher biomass than the control (0% plant population). As a result, the surface residue cover in the fall season following shredding was not different between the 50% and 100% treatments. However, significant differences were found in surface residue cover with time with sharp increases after harvest, followed by gradual decreases due to residue weathering, then sharp decreases in the subsequent spring due to residue incorporation by disking.

Residue cover was shown to be highly dynamic as a result of weathering and incorporation. These temporal changes in residue cover had significant impacts on the runoff and erosion control. Soil loss was reduced by 47% and 50%, respectively, for the 50% and 100% plant populations. Even though the land was left fallow for a year then NT planted the following spring, the erosion protection afforded by residue cover had been essentially lost. This work emphasizes the importance of residue management and that temporarily converting land to NT for a season provides minimal soil erosion protection if the residue cover is not properly maintained.

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